NASA Wearable Technology CLUSTER 2013-2014 Report

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Executive Summary

By all measures, the 2013-2014 academic year was an enormous success for the Wearable Technology CLUSTER. New universities and NASA mentors were added to the partnership, doubling the number of student participants and significantly increasing attendance at the Wearable Technology Symposium. Students, professors, and NASA mentors provided overwhelmingly positive feedback on the value of the partnership – a transformative experience that motivates student teams to learn and achieve results that have direct benefits to NASA's human spaceflight mission.

Significant highlights and outcomes from 2013-2014 include:

- Students from many participating universities will present their projects at top academic conferences in the fall. Past projects have been very successful in design competitions.
- Several teams have continued their work as senior design and directed research projects. NASA mentors continue to guide these projects.
- Three participating students served as summer interns at the Johnson Space Center.
- 20% of the University of Minnesota Apparel Design class of 2014 has been accepted to graduate school, up from 0% applying before the CLUSTER began.
- Dr. Lucy Dunne at the University of Minnesota was awarded NASA's prestigious Silver Achievement Medal. Dr. Dunne continues to research e-textile manufacturing with JSC.
- Drs. Tom Martin and Paola Zellner at Virginia Tech received the university's 2014 XCaliber Award for outstanding contributions to technology-enriched active learning.
- A Wearable Technology Design Lab has been formed at the Brooklyn Fashion and Design Accelerator. Pratt's Rebeccah Pailes-Friedman serves as Wearable Tech Research Fellow.

The Wearable Technology CLUSTER (Collaboration for Leveraging with Universities in Space Technology Engineering and Research) is an informal partnership between the NASA Johnson Space Center (JSC) in Houston and professors at multiple universities. In the 2013-2014 academic year, participating universities included the University of Minnesota, Georgia Tech, Virginia Tech, Pratt Institute in New York, Texas A&M University, and the University of New Hampshire. The CLUSTER is funded primarily by NASA's network of Space Grant Consortia. It focuses on student projects that address human spaceflight challenges related to wearable technology. Each spring, students present their projects each spring at the annual Wearable Technology Symposium at the Johnson Space Center.

The Wearable Technology CLUSTER began in spring 2012 with six projects in the University of Minnesota Apparel Design program. The collaboration was funded by the Minnesota Space Grant Consortium and mentored by JSC engineers and scientists. Student teams presented their projects at the first Wearable Technology Symposium at the Johnson Space Center in Houston. In the spring of 2013, courses at Georgia Tech and Virginia Tech were added to the CLUSTER, doubling the number of student participants. The expansion has continued through the 2013-2014 academic year (see Appendix I).

The Wearable Technology CLUSTER and Symposium have proven to be valuable assets for all involved. The collaboration continues to facilitate transformative student experiences and the development of wearable technology capabilities that advance NASA's Space Technology Roadmaps.

Contents

Introduction

This report summarizes the Fall 2013 through Spring 2014 activities and outcomes for the NASA Wearable Technology CLUSTER (Collaboration for Leveraging Universities in Space Technology Engineering and Research). The CLUSTER is an informal partnership between the NASA Johnson Space Center (JSC) in Houston and professors at multiple universities. In the 2013-2014 academic year, participating universities included the University of Minnesota, Georgia Institute of Technology (Georgia Tech), Virginia Polytechnic Institute and State University (Virginia Tech), Pratt Institute in New York, Texas A&M University, and the University of New Hampshire. This report includes sections written by NASA personnel and university professors, providing background and observations from each perspective.

The CLUSTER is made possible through funding provided by NASA's network of Space Grant Consortia. It is primarily focused on enabling student projects that address human spaceflight challenges related to wearable technology. In the 2013-2014 academic year, a total of 97 graduate and undergraduate students worked on 24 projects, guided by mentors from a wide range of JSC organizations. Their efforts culminated in the third annual Wearable Technology Symposium at JSC, in which the students presented their final products to mentors, fellow students, and the JSC community.

By all measures, the 2013-2014 academic year was an enormous success for the Wearable Technology CLUSTER. New universities and NASA mentors were added to the partnership, doubling the number of student participants to nearly 100 and increasing attendance at the wearable technology symposium by 25% (see Appendix I). Students, professors, and NASA mentors provided overwhelmingly positive feedback on the value of the partnership. Perspectives from NASA mentors and the largest university partners are included in this report.

Kaila Eckers: 2012 CLUSTER Alum

Kaila Eckers, a 2013 graduate of the University of Minnesota Apparel Design program, participated in the first Wearable Technology CLUSTER and Symposium in the spring of 2012. The following summer, Kaila applied the skills she developed while working on her project to an internship at the NASA Johnson Space Center, where she helped design and manufacture a reconfigurable electronic-textile garment. Spurred by her experiences, Kaila has since pursued a career in wearable technology. She now serves as Chief Design Officer at Playtabase, a Minneapolis start-up that is developing a wearable device to control household electronics through simple intuitive gestures.

Kaila's story is one example of how the Wearable Technology CLUSTER, through the support of NASA's Space Grant Consortia, is broadening perspectives and revealing opportunities for the next generation of innovators.

Wearable Technology Background

Wearable technology has the potential to revolutionize the way humans interact with one another, with information, and with the electronic systems that surround them. This change can already be seen in the dramatic increase in the availability and use of wearable health and activity monitors. These devices continuously monitor the wearer using on-body sensors and wireless communication. They provide feedback that can be used to improve physical health and performance. Smart watches and head mounted displays are also receiving a great deal of commercial attention, providing immediate access to information via graphical displays, as well as additional sensing features.

For the purposes of the Wearable Technology CLUSTER, wearable technology is broadly defined as any electronic sensing, human interfaces, computing, or communication that is mounted on the body. Current commercially available wearable devices primarily house electronics in rigid packaging to provide protection from flexing, moisture, and other contaminants. NASA mentors are interested in this approach, but are also interested in direct integration of electronics into clothing to enable more comfortable systems.

For human spaceflight, wearable technology holds a great deal of promise for significantly improving safety, efficiency, autonomy, and research capacity for the crew in space and support personnel on the ground. Specific capabilities of interest include:

- Continuous biomedical monitoring for research and detection of health problems
- Environmental monitoring for individual exposure assessments and alarms
- Activity monitoring for responsive robotics and environments
- Multi-modal caution and warning using tactile, auditory, and visual alarms
- Wireless, hands-free, on-demand voice communication
- Mobile, on-demand access to space vehicle and robotic displays and controls

Many technical challenges must be overcome to realize these wearable technology applications. For example, to make a wearable device that is both functional and comfortable for long duration wear, developers must strive to reduce electronic mass and volume while also addressing constraints imposed by the body attachment method. Depending on the application, the device must be placed in a location that the user can see and reach, and that provides the appropriate access to air and the wearer's skin. Limited power is available from body-worn batteries and heat must be managed to prevent discomfort. If the clothing is to be washed, there are additional durability and washability hurdles that traditional electronics are not designed to address. Finally, each specific capability has unique technical challenges that will likely require unique solutions.

In addition to the technical challenges, development of wearable devices is made more difficult by the diversity of skills required and the historic lack of collaboration across domains. Wearable technology development requires expertise in textiles engineering, apparel design, software and computer engineering, electronic design and manufacturing, human factors engineering, and application-specific fields such as acoustics, medical devices, and sensing. Knowledge from each of these domains must be integrated to create functional and comfortable devices. For this reason, the diversity

of knowledge and experience represented in the Wearable Technology CLUSTER is critical to overcoming the fundamental challenges in the field.

Project Initiation and Funding

Each professor in the Wearable Technology CLUSTER integrated the student projects into an existing project-based course at their respective university. JSC engineers and scientists submitted brief project descriptions that were related to ongoing or future needs. Project requirements and deliverables were shaped collaboratively between professors and JSC mentors based on student abilities and mentor need, with all projects requiring some form of demonstration. Mentors presented problem statements to each university via videoconference, and student teams selected or were assigned projects or based on their interest. Mentors provided context and guidance throughout the students' work, and the students delivered interim products based on their respective course requirements.

Students were able to participate in the Wearable Technology CLUSTER thanks to funding provided by NASA's network of Space Grant Consortia – the Minnesota, Georgia, Virginia, and New York Space Grants. This funding, in some cases supplemented by the universities, covered costs associated with project materials, as well as travel to the symposium for students and professors. This funding was critical to the success of the CLUSTER, expanding the number and diversity of student participants, as well as JSC engineers and scientists who otherwise would not have been able to sponsor a project.

Wearable Technology Symposium

Student projects culminated in presentations and demonstrations at the third annual Wearable Technology Symposium held on April 21, 2014, at the Johnson Space Center. The symposium was an opportunity for students and mentors to have face-to-face interactions, enhancing the students experience and ensuring mentors received a detailed explanation of student work. The full day event included presentations by student teams, NASA scientists and engineers, a poster session, prototype demonstrations, and a tour of JSC facilities. See Appendix III for the full schedule of the 2014 Wearable Technology Symposium.

Figure 1. Wearable Technology CLUSTER student participants during the Wearable Technology Symposium on April 21, 2014, at the NASA Johnson Space Center

NASA Perspective

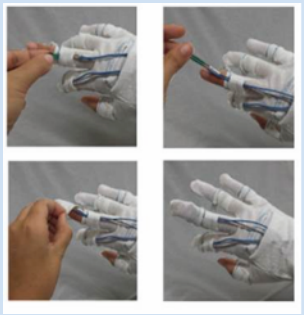
Cory Simon

Mentors from a variety of disciplines at the Johnson Space Center submitted problem statements for the students. Thanks to funding from the Space Grant Consortia, mentors were not responsible for funding the student projects, allowing engineers and scientists to submit problem statements regardless of their available funds. This resulted in a greater quantity and diversity of project options for the students. In response to a follow-up survey, mentors indicated they primarily submitted projects because they wanted the students to discover and explore alternative approaches to solving a real problem in their work. Some problems were not currently being addressed, but would be important to future work, while others were being actively addressed but the engineer or scientist had exhausted obvious solutions. Mentors also took advantage of the students' skills in areas where the mentor lacked expertise, primarily in apparel design.

Each student team focused intently on a problem for a minimum of four months. In general, they spent time understanding the need, users, and context, conducting literature reviews and market surveys, brainstorming solution alternatives, and building multiple prototypes. The projects have served as useful test-beds to explore how wearable technology can address specific needs related to NASA's Space Technology Roadmaps. Despite their lack of experience addressing spaceflight challenges, or more likely because of it, the teams produced a wide variety of creative solutions. This intensive exploration would not have occurred or would have been significantly delayed without the students involvement in the projects.

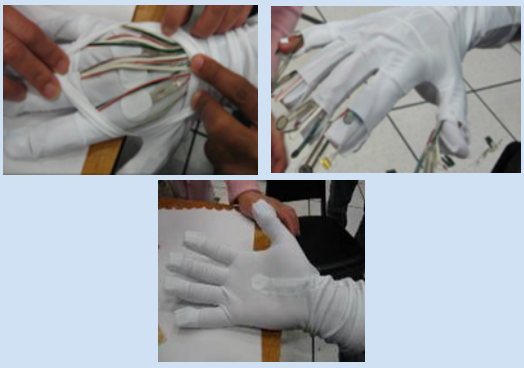
Immediate Impact: Sensors for Space Suit Gloves

Two student teams accepted NASA's challenge to integrate dozens of sensors into the space suit gloves. Following the teams' demonstrations, their designs and findings were integrated into a final prototype to support pressurized testing in a glove box. NASA now has more data than ever on the conditions in the space suit gloves – critical information for preventing hand injuries to astronauts.



The Georgia Tech team's final prototype

The Virginia Tech team's final prototype



NASA's integrated sensor gloves used for testing

Many of the prototypes were immediately useful and others explored ideas that will be evaluated further in the future. Some mentors found the specific tools, materials, or manufacturing techniques to be most useful, while others benefited from the students' research and integrated demonstrations. Overall, feedback from mentors was extremely positive and each expressed interest in participating again in 2014-2015.

The exchange of ideas and community building among mentors continues to be a powerful asset for NASA. Mentors found common ground as a result of the CLUSTER's focus on wearable technology. Feedback indicates mentors identified opportunities to collaborate across NASA organizations and found useful ideas in projects they did not mentor. The Wearable Technology Symposium was the primary forum for this exchange of ideas. Mentors, students, professors, and many from the JSC community were able to informally discuss challenges and solutions, stimulated by the students' prototypes.

NASA has also benefited from follow-on activities. Three University of Minnesota Apparel Design students served as interns during the summer of 2014. Their unique expertise has supported research and development in wearable device attachment methods and electronic-textile manufacturing. Two interns were funded by the Minnesota Space Grant Consortium and one by a National Science Foundation research grant. Other student teams, with continued guidance from JSC mentors, have continued their projects as thesis and capstone projects.

NASA Mentor Feedback

Mentors were asked to respond to a follow-up survey on the value of their participation in the CLUSTER. Selected questions and responses are below:

Were the students' results useful? How?

"Yes, both the Georgia Tech and Virginia Tech glove designs were useful. In particular, the sensor carrier gloves that they designed showed us concepts of how wire routing could be done, finger and hand ports could be accessed through the glove, and how multiple layers of fabric could be utilized to route wiring and protect the sensors."

"Yes. The students explored multiple technical approaches to solving the problem (Kinect-based finger tracking, custom video-based) and considered both the technical and the human factors needs. If we continue with plans to implement a tactile feedback system in the virtual reality dome, we now have a firm starting point"

"Though there was some overlap in approaches among teams, generally the students tackled the problem in different ways. The results were a creative array of possible methods/technologies to pursue down the road."

Did you find the Symposium beneficial?

"The symposium was amazing! It was great to get that much creative energy into one room. It was good for NASA/student interaction, but it was also good for student/student interaction."

"Definitely useful. The symposium allowed mentors the ability to see their university products in live demonstration during the presentation. It also allowed time to talk with the students in person and see the product they had worked on."

"The symposium was beneficial as it provided an opportunity to discuss with the students, in person, their projects along with providing an opportunity for the students to gain experience presenting their work."

"Yes, absolutely. The symposium allowed us to see the students' final product in person and discuss their design process and outcomes. It forced the students to develop a fully functioning system, including a demonstration environment that allowed us to see it in action. We were able to engage with each student and ask specific questions about their domain."

Did you find other mentors' projects useful? Do you see potential for collaboration as a result of your participation?

"Yes. In general I found many/most of the design solutions to be creative and stimulating."

"Somewhat. Wearable technology projects in general are interesting to me. Talking to the students about their manufacturing methods and with other mentors about their wearable technology needs was helpful."

"The bag redesign was particularly interesting to me. Learning how to reuse and re-purpose existing items will help NASA long-term."

University Perspective: University of Minnesota

Dr. Lucy Dunne

Funding Source

Minnesota Space Grant Consortium
Director: Dr. William Garrard
Associate Director: Dr. James Flaten

Faculty Background

Dr. Lucy Dunne
Associate Professor, Dept. of Design, Housing, and Apparel
Director of the University of Minnesota Wearable Technology Laboratory
Dr. Dunne's ongoing research focuses on wearability, new functionality, and mass-manufacture of wearable technology, smart clothing, and e-textiles.

Course and Student Background

ADES 3224: Apparel Design Studio IV: Functional Apparel Design

This is a required course that is restricted to junior-level Apparel Design majors. At this point in their degree, the students have a background in apparel design, patternmaking, and construction, but have no engineering background. Following graduation, these students are typically employed as creative or technical apparel designers in the ready-to-wear garment industry. Some go into parallel fields such as journalism, costume design, or functional clothing.

The course is structured as a studio course with a semester-long project in parallel with learning new content by lecture, hands-on exercises, reading, and quizzes. The project begins with an intensive library research phase in parallel with introduction of new content (basics of functional apparel design). A laboratory/design research phase follows in which research questions that are essential to the development of an ultimate design are identified and answered. The project concludes with a final design iteration in which works-like and/or looks-like prototypes are completed.

The primary course topics include thermal transfer and thermal balance in clothing (insulation, moisture transport), impact protection in apparel (basic mechanics, design strategies), human motion and mobility (patternmaking for mobility), e-textiles and smart clothing (including basics of electricity), physiology and psychology of human comfort (with a little human-computer interaction). The UMN Apparel Design program is one of the only apparel programs nationwide that requires a functional clothing course. We are also rare in emphasizing e-textiles and smart clothing in a hands-on, explicit-instruction way.

DES 5195: Human Factors in Design

This course is a mix of graduate (MA, MFA, MS, and PhD) and some undergraduate students. Students have a wide variety of backgrounds, as the course meets degree requirements in Apparel Studies, Graphic Design, Interior Design, and Human Factors, but approximately half of the enrollment is typically students taking the course as an elective. The students' abilities vary widely with some engineers, some designers, and some human factors students.

The course is primarily lecture-based, with two design projects at the end of the course. Projects begin as content is concluded – first, an analysis project in which human factors of a problem domain are identified and analyzed, and second, a design project in which this understanding is applied to the development of a novel solution. The analysis project uses an existing solution to help the student analyze the human factors of the problem. The design project uses a user-interactive, human-centered design process to develop an effective and novel solution to a problem.

The course is a standard introductory overview of human factors, with an emphasis on applying content knowledge to design. The primary course topics include basic anatomy and physiology, sensory perception (visual, auditory, tactile/vestibular), attention, decision-making, emotion, and affect.

Benefits of Projects with NASA

As always, a NASA project is exceptionally motivating for many students. The in-person presentation of results and interaction with NASA mentors is crucial to that experience – in our programs we do many industry-collaborative projects with "big name" companies, so in some ways students can be a little jaded about "real world" projects. However, the NASA name elevates the standard above what they are used to, and the collaborative aspect (teleconferencing with mentors, presenting in person) reinforces the "realness" of the project.

Figure 2. University of Minnesota professor Dr. Lucy Dunne discusses her students' project with their mentor, Lindsay Aitchison, during the Wearable Technology Symposium.

Each year we have at least one project with staying power that achieves something beyond the classroom experience. Similarly, each year we have one or two students who are exceptionally inspired by the experience and emerge with a new direction for their studies and career. These are often the projects and students that develop into larger research projects and graduate students.

Benefits of the Wearable Technology Symposium at JSC

I believe the symposium is perhaps the most crucial element of the collaboration. Travel experiences are almost always transformative, and many of our students have very few opportunities to travel (we have had several students for whom this trip was their first time on an airplane!). In addition, the chance to tour JSC and meet with NASA engineers and designers is an amazing role-modeling experience. Without the trip I think this would feel much like many of their other industry projects – it would resonate with a few students, but wouldn't be the intense motivator that it currently is. I have rarely seen final presentations from students at this level that achieve the standard that is normal at the symposium.

Partnership Outcomes

Figure 3. University of Minnesota students Melissa Ellingson (left) and Katie Mueller (right) listen to fellow student presentations during the Wearable Technology Symposium.

Following the Spring 2013 Wearable Technology CLUSTER activities, several success stories continued to take shape that were not included in the Spring 2013 Report. These outcomes, as well as the 2013-2014 outcomes, include:

- The 2014 UMN undergraduate Apparel Design class saw a 25% increase in the number of students applying to graduate school, with 20% of the class accepted to and attending graduate school in the fall. This increase is directly tied to interest in functional clothing and wearable technology.
- Dr. Lucy Dunne was awarded NASA's prestigious Silver Achievement Medal for "her major contributions to NASA's core value of teamwork and core mission of sharing knowledge gained in space technology with researchers, universities, and educators."
- A team of five students continued collaborating with their NASA mentor to refine and evaluate their solution to moisture transport challenges in the space suit. This project was accepted to NASA's Reduced Gravity Education Flight Program and tested in microgravity in the summer of 2014. The team was the subject of several university press releases and external media coverage (local TV and newspaper).
- Three Apparel Design students participated in NASA internships at the Johnson Space Center in the summer of 2014. These students worked on wearable technology projects in the Wearable Electronics Application and Research (WEAR) Lab and in the Habitability Design Center.
- One Spring 2013 student continues to serve as a Research Assistant in the UMN Wearable Technology Lab, funded by Dr. Dunne's NSF CAREER Award.
- Multiple projects were accepted to the wearable technology juried exhibit and design competition at the International Symposium on Wearable Computing

Student Feedback

Students were enthusiastic and very positive in their post-course evaluations:

- "I loved this class, it really broadened my horizons and opened up a lot of new possibilities for the future."
- "Love the concepts in this class. The NASA project was a hugely influential project that has changed some things for my future."
- "I really enjoyed this class even with all of the work that was involved."
- "I really enjoyed this class. It was a tremendous amount of work, but I learned so much. It also introduced me to wearable technology which is awesome :)"

University Perspective: Georgia Tech

Clint Zeagler

Funding Source

Georgia Space Grant Consortium
Director: Dr. Stephen Ruffin
Program Manager: Wanda Pierson

Faculty Background

Clint Zeagler
Research Scientist, School of Industrial Design
Clint's diverse background in fashion, industrial design, and textiles drives his research on electronic textiles and on-body interfaces with the Contextual Computing Group of the GVU Center at Georgia Tech. As a Research Scientist I for the Georgia Tech School of Industrial Design he teaches courses on Wearable Product Design and Mobile and Ubiquitous Computing (MUC). His prior and ongoing research includes the development and application of the ESwatchBook, a tool to facilitate interdisciplinary collaboration in wearable computing, and FIDO: Facilitating Interactions for Dogs with Occupations, a project to enhance interactions between service dogs and their owners.

Course and Student Background

CS7470/ID8900: Mobile and Ubiquitous Computing (MUC)

This course is offered by the School of Interactive Computing and the School of Industrial Design at both an undergraduate and graduate level. MUC is a 3 credit hour lecture course with project outcomes where Industrial Design students work on teams with Computer Science students. Project ideas are pitched at the beginning of the course and student groups decide on a project topic within the framework of the course topics, (usually teams form around ongoing research projects or other projects with dedicated mentors).

Course topics include:

- Privacy
- Wearability of technology
- Human movement and mobility, patterning for mobility
- Ubiquitous computing and environmentally embedded computing
- Location aware computing
- E-textiles and advanced materials
- Sensory perception (visibility, tactile perception)
- Wearable interface design

Figure 4. Georgia Tech student Andrea Hunt presents her team's work on wearable sensors for space suit gloves.

Teams form using a web-based message board, and after deciding on a project contact their mentor and begin researching. Some teams focus on working toward prototypes to solve

problems, while other teams create Human Computer Interaction studies to answer questions. The course is split into two project deliverable deadlines. At the midterm, the project is reviewed and critiqued, students take this feedback from course instructors and mentors and use it when finishing the semester long project.

Class projects are presented to the class at the end of the semester, and presentation is counted as a portion of the project grade. Students are also required to write a four-page ACM style academic paper.

Benefits of Projects with NASA

In a class of 100 students, 25 students chose to work on projects mentored by NASA engineers and scientists, forming five teams. Each student team worked with a NASA mentor who was readily available and actively involved in answering questions and guiding teams. Many of these students started to understand the complexity of designing for space, and also the opportunities for working with or for NASA in the future.

Figure 5. Georgia Tech students visit the Saturn V Rocket at JSC's Rocket Park.

Benefits of the Wearable Technology Symposium at JSC

The symposium is an integral part of the experience and a major factor in why the students enjoyed working with NASA so much. Not only were students able to take a tour of JSC and show their work to their mentors in person, but also many people from JSC who were not directly involved in the mentoring process stopped by to view their work. One major value added by the symposium is that the students can also meet their counterparts from other universities, and engage with them on how their design process differed. Students highly valued hearing presentations from NASA scientists and engineers.

Both the poster session and presentation gave the students a memorable and rewarding experience, very close to what it is like to present work at an academic conference.

Partnership Outcomes

Before we start with the outcomes from the Spring 2014 projects I would like to touch on a few significant outcomes from Spring 2013 projects that have not been reported yet. Select GT projects from Spring 2013 were exhibited at the International Symposium of Wearable Computing in Zurich, Switzerland, as part of the ISWC 2013 Design Exhibition. Georgia Tech 2013 projects were also exhibited at the Solid Wearable Tech Showcase in San Francisco. This goes to show the extended life and outreach these projects have, carrying the NASA name and Georgia Space Consortium Grant influence further afield than the initial JSC Symposium.

Five projects were completed with NASA mentors in spring 2014: Wearable Sensor Garments for EVA Gloves, Wearable Unobtrusive Noise Canceling Vest, Posture Sensing Garment, Hands-free Jetpack Controller, and One-Handed Input Device. Of the 25 students who participated in project groups working on NASA sponsored projects, 19 students came to the JSC Wearable Technology Symposium. Projects from this spring have been submitted to numerous competitions and conferences. We hope to see some of the projects this fall at the Design Competition for the International Symposium on Wearable Computing (ISWC).

Figure 6. Georgia Tech students demonstrate their projects for mentors and fellow students during the poster session at the Wearable Technology Symposium at JSC.

Student Feedback

"During the spring 2014 semester, I had the opportunity to participate in Georgia Tech's CS 7460 Ubiquitous Computing course. As part of the semester-long project in this course, I had an incredible experience working with NASA to develop a wearable unobtrusive noise-canceling vest intended for astronauts on the International Space Station. NASA's mentor Robert Trevino provided guidance with use context, design concepts, and overall project requirements. From there, we were able to devise our own original technology and design that utilized the group's diverse expertise. Teamed with an industrial designer, two computer scientists, and an electrical engineer, I was able to collaborate with a motivated team until we ultimately developed and tested our prototype. We were able to achieve drops of up to 10dBSPL with various test signals.

"The culmination of our project was in Houston, Texas, where we presented our work at NASA's Johnson Space Center Wearable Technology Symposium. Students from all over the country were in attendance to share their work on a multitude of sophisticated projects. The entire visit was a great experience as the clientele was made of students from many different backgrounds including design, engineering, fashion, and computing. Outside of the presentations, discussing technical approaches with fellow engineers and hearing the design methodology of students from vastly different programs such as fashion and clothing design were very informative for me. I am very grateful for the experience that Georgia Tech and NASA have provided for all of us involved, and I hope to continually foster the relationship between both organizations."

-Riley Winton, MS-HCI Georgia Tech

University Perspective: Virginia Tech

Dr. Tom Martin

Funding Sources

Virginia Space Grant Consortium
- Director: Mary Sandy
- Deputy Director: Chris Carter

Virginia Tech Institute for Creativity, Arts, and Technology (ICAT)
- Director: Ben Knapp

Faculty Background

Dr. Tom Martin
- Professor, Electrical and Computer Engineering and (by courtesy) School of Architecture + Design
- Senior Fellow, Institute for Creativity, Arts, and Technology (ICAT)
- Co-director of the Virginia Tech Electronic Textiles Laboratory
- Dr. Martin's research focuses on wearable computing, electronic textiles, and interdisciplinary design of intelligent devices.

Dr. Paola Zellner
- Assistant Professor, Architecture
- Professor Zellner's research interests include material, mainly textile media, and responsive environments, with a focus on the exploration of form and space through the fabrication of textile constructs, at the convergence of art, design, and technology.

Course and Student Background

ARCH 3514: Textile Space

CS 2984/ARCH 3514: Introduction to Physical Computing

The projects involved 16 undergraduate students from Virginia Tech's College of Architecture and Urban Studies and College of Engineering. Students participated in the projects as part of the Architecture 3514 Textile Space course and as part of the CS 2984/ARCH 3514 Introduction to Physical Computing course. The Physical Computing course was sponsored and hosted by the Virginia Tech Institute for Creativity, Arts, and Technology. Students in the course ranged from sophomores to seniors, so there was a wide range of technical backgrounds and experience.

Students in the course were presented with the list of possible projects in January, and five teams were selected for NASA projects (four teams in the Physical Computing course and one team in the Textile Space course). The projects selected included the noise cancelling vest, one-handed keyboard, EVA interactive cuff checklist, wearable sensor garments for EVA gloves, and radiation shielding garment from modified cargo transfer bag. The prototypes for the noise canceling vest, cuff checklist, and radiation shielding garment are shown in Figure 7, Figure 8, and Figure 9

Figure 7. Diagram (left) and final prototype (right) of the noise cancelling vest concept.

Figure 8. Prototype of flexible cuff checklist.

Figure 9. Virginia Tech student Dan Duminuco demonstrates the transformation of the modified cargo transfer bag (left) to a radiation-shielding garment (right)

This spring was the first offering of the Physical Computing course. The course required the students to complete four individual projects using the Arduino microcontroller board and programming environment, as well as one large team project. The course met twice a week, with the first meeting of most weeks spent introducing a new topic and the second meeting spent working on the team projects.

This course was intended to give students a hands-on introduction to physical computing, where computing mediates a person's interactions with the environment. The course was run in a studio setting, providing students with an exposure to a variety of prototyping and implementation techniques.

Using simple microcontroller boards such as the Arduino and Raspberry Pi, along with sensors, actuators and other electronics, students created interactive and responsive devices, installations, and environments. The course took a human-centered design approach to exploring the range of expressions and affordances provided by physical objects whose response is determined by computation.

Benefits of Projects with NASA

There were several benefits of the projects with NASA for the students and faculty at Virginia Tech. For the students, the projects presented them with an open-ended, real-world design problem. Interacting with the mentors was also a major benefit for the students, particularly in discovering the nuances of the design constraints.

Benefits of the Wearable Technology Symposium at JSC

The Wearable Technology symposium was also a very good opportunity for the students because it gave them a chance to see other approaches to the same design problem. On the return trip and in their final reports, many of the teams described the value of the feedback they received from their presentations and posters from both the mentors and from student teams from other universities. Finally, the students greatly enjoyed the tour of JSC after the presentations and poster session. For the faculty, the symposium was an excellent opportunity to discuss potential research collaborations with NASA personnel.

Partnership Outcomes

Paola Zellner and Tom Martin received Virginia Tech's 2014 XCaliber Award for excellence as an interdisciplinary team making outstanding contributions to technology-enriched active learning for the Textile Space class in spring 2013. This was the course that was used for the NASA Wearable Technology student projects. The award was announced in April and will be presented in September.

Student Feedback

Due to the limited travel funds available, only some of the students in the Physical Computing class were allowed to work on the NASA projects, and not all of the students were able to travel to JSC. The students on the NASA projects were enthusiastic about the opportunity throughout the semester. Many of the students on the other projects in the course understood the travel situation, but expressed the hope that in the future everyone who wanted to work on the NASA projects would be able to.

One student is very interested in continuing to work on the radiation-shielding garment as part of her senior year project in the upcoming school year. Following are some of the comments received from students in the Physical Computing class:

"Presenting at NASA really helped my interest in wearables; I want to figure out where to get into this stuff as a career."

"This was a thoroughly enjoyable project that was both challenging and exciting."

"Having the NASA sponsored projects were neat, even though I was not a part of a NASA project."

University Perspective: Pratt Institute

Rebeccah Pailes-Friedman

Funding Source

New York State Space Grant Consortium
Director: Dr. Yervant Terzian
Associate Director: Erica Miles

Faculty Background

Rebeccah Pailes-Friedman
Associate Professor, School of Design
Wearable Technology Research Fellow, Brooklyn Fashion and Design Accelerator
Professor Pailes-Friedman's work focuses on wearable computing, electronic textiles, and interdisciplinary design of intelligent devices and athletics. Rebeccah is pioneering research in design methodologies, smart materials, and wearable technology. Professor Pailes-Friedman has held positions as Design Director for Fila, Champion, and Nike, and teaches in both the Fashion and Industrial Design departments at Pratt, where she has developed and teaches courses on Functional Apparel, Activewear, Athletic Equipment, Soft Products, and Wearable Technology. Her work has been published internationally and she is the author of the upcoming book *Designing with Smart Textiles*.

Course and Student Background

IND-301: Junior Design Studio

The E-SEWT, wearable technology project was conducted in one section of IND-301, Junior Design Studio. The course is part of the undergraduate Industrial Design curriculum at Pratt Institute. IND-301 is required for all junior level industrial design majors and is 4 credits. It meets twice a week for 3 hours and is structured as a hands on studio design class.

During the course of this studio, students conduct in-depth research surrounding wearable technology and develop solutions that address a specific problem they identify within the E-SEWT project. Using a more scientific approach to product design, students developed a series of inquiries surrounding the project and used Arduino coupled with various electronic sensors, actuators, LEDs and other devices to conduct their design exercises. Initially, students worked independently, but over the first few weeks groups were formed to prototype four solutions addressing different aspects of the design problem; including the attachment of the swatches, flexibility of the garment, ease of use, and intuitive user interfaces.

The semester's project was also a dual collaboration with NASA's Wearable Electronics Application and Research (WEAR) Lab and the University of New Hampshire. A partnership was formed with Dr. Andrew Kun, a professor at the University of New Hampshire in the Electrical and Computer Engineering Department. Students from his Ubiquitous Computing class worked with the Pratt students to collaborate over distance on the E-SEWT project. Students spent the entire semester working in tandem with the students from UNH, to develop solutions to the problem posed in the NASA project. The goal was to give the students a "real-world" experience. By creating a collaborative work experience between the two classes, students had to learn to communicate their ideas clearly in videoconference, email, and chat supported by a few in-person meetings.

The structure of the Pratt/UNH collaboration consisted of 4 formal full-class meetings. Two by video-conference and two in person all day field trips. Subsequent weekly touch-base meetings were strongly encouraged, and were planned and executed by each group outside of class time. The final deliverable included a finished working prototype, a video of their project in action, and a brief research paper.

Figure 10. Pratt students (left to right) Kai Lin, Eleni Skourtis-Cabrera, Carla Ramirez, Violet Tamayo, Theo Ferlauto in front of their posters at the Wearable Technology Symposium.

The project was conducted in six phases:

1. **Background research –**
   Students began their investigation into solving the E-SEWT design problem with a phase of in-depth literature and image research. Each student was required to study functional clothing and gain an understanding of body movement, range of motion, fit, and attachment methods of clothing. They also did research on what life is like on the International Space Station and how they thought they could address astronaut needs that may not be outlined in the specific brief to bring components of "added value" to the project.
2. **Design ideation –** Students then completed a creative ideation process to generate alternative approaches to solving the design problem they had identified. The idea of a problem within a problem is a key component of working in the design process and within the context of the class.
3. **Prototyping and experimentation –** After the research and ideation phase, groups were formed to work on four hybrid-prototypes that combined design details from individual team members into one unifying design for each group. An engineer from UNH was assigned to each group to work on the development of one particular component swatch for each group's E-SEWT solution. Different members of each group led specific tasks including:
   a. Patternmaking and sewing the garment models and the final prototype
   b. Building the electronic components and programing the Arduino swatches
   c. Designing the connection between the garment and the swatches
   d. Communication, documentation, presentation materials, and continued research

4. **Creation of final prototype –** the group worked to build multiple iterations of each swatch connection and garment element. Once as many design issues as possible were resolved, a final prototype was created. The prototypes were fully functional and had electronic capability.
5. **Testing –** At the conclusion of the semester, the UNH students traveled to Brooklyn to participate in a full day of wear testing that was conducted on the Pratt campus. The test subjects were students unfamiliar with the project and after donning and executing specific movements in their assigned prototype were asked to fill out a questionnaire. The questions were designed to determine how well the garment and the swatch connections functioned in terms of fit, range of motion, ease of use, and intuitiveness.
6. **Presentation –** The class concluded with a final presentation to a jury of critics. Among the critics were faculty, administration, and invited guests including Ted Southern and Nikolai Moiseev of Final Frontier, a Brooklyn-based startup company specializing the in the design and production of space suits. The students were required to present their design process in both a large collection of wall-based images and in a video that captured the functionality and use of their projects.

Benefits of Projects with NASA

The collaboration with NASA offers students a unique opportunity to approach industrial design from a research perspective and exposes them to an area of design they may not have previously considered. Working with NASA elevated the expectations of the students and the level of their work. They worked hard to create something that they considered 'NASA-worthy.'

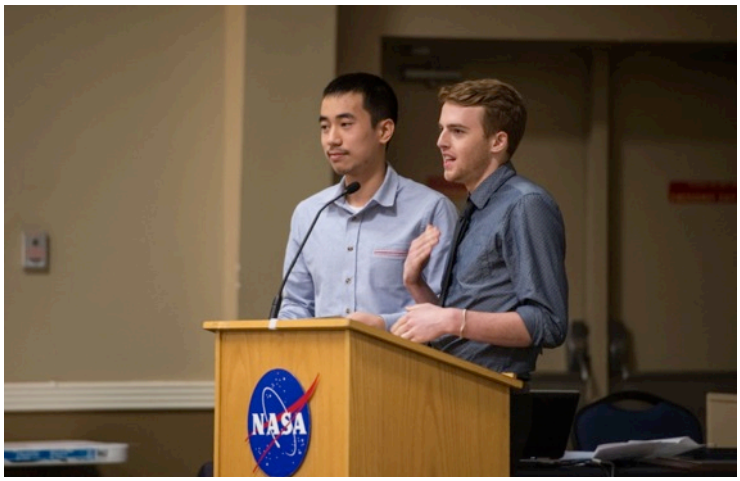


Figure 11. Pratt students Kai Lin and Cody Miller present their work at the Wearable Technology Symposium.

As the project progressed, students began to feel empowered by their progress and found that by working together in small groups they could achieve more together than they could individually. At first, the group aspect of the project was challenging for them to master. They had to learn to work together and then to collaborate further with the UNH engineering students, all while taking direction and feedback from their NASA mentor. Their feedback was that they learned a lot from working with non-designers and from their fellow group members.

Benefits of the Wearable Technology Symposium at JSC

Students' participation in the JSC Symposium was an added benefit for the students who were able to travel. The Pratt course is offered in the fall semester and many of the students who were in the class had other obligations or could not afford to attend. For those who did, they saw their work in context of

the many projects from the other much larger universities. Pratt's entire undergraduate student population is 3,500 and there are only 200 undergraduate students in the industrial design department. The Institute has no engineering, or science majors.

Many of the project groups from the other schools had student groups that were integrated with different types of engineers and perhaps one industrial designer. It was after traveling to JSC for the Symposium that the Pratt students began to see the value and benefit of working in groups and the collaboration with University of New Hampshire.

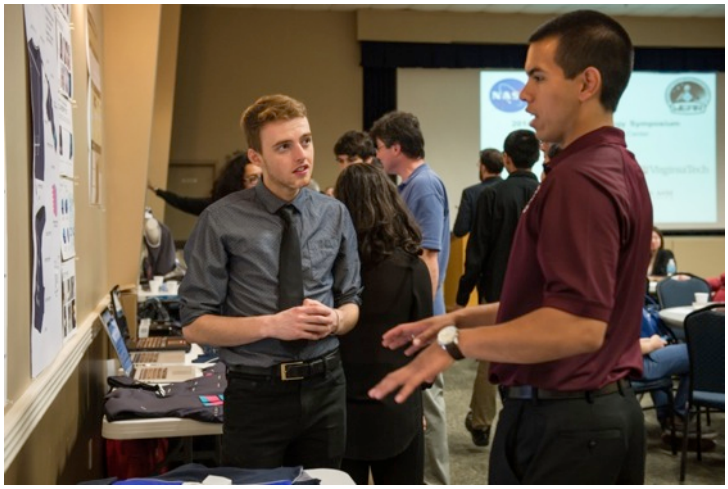
Finally, the poster session was by far the students' favorite. The interaction with the students from the other universities, designers and engineers alike, is something that the Pratt students are still talking about. They liked seeing the other students' work and then the interaction to learn the details of their projects and process. It also helped them put their work in perspective and gave them confidence that their work was valuable and their solutions were innovative.

Partnership Outcomes

One of the strongest aspects of the project was the frequency and availability of their interaction with their NASA mentor, who they found to be inspirational and approachable. The energy and spirit in the class was contagious and many of the students have since decided to pursue design careers specializing in wearable technology and other engineering-based collaborative design disciplines.

Further, one of the most unique aspects of the project was the student's ability to design for a unique environment: micro-gravity. A key to becoming a successful designer is to be able to empathize with their user.

Finally, the outcomes from the project have led to conference submissions, the development of functional



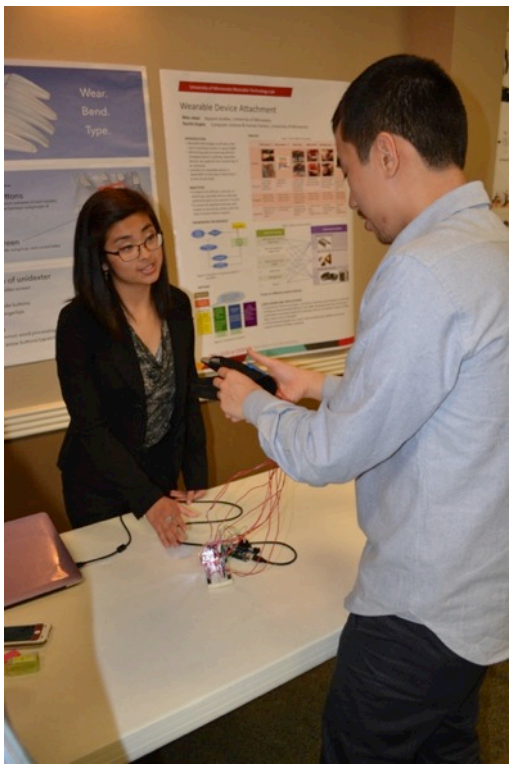


Figure 12. The Symposium allowed teams with different backgrounds and expertise to discuss how they addressed the NASA projects. (Left) Pratt student Cody Miller discusses his project with Texas A&M student Andrew Butler. (Right) Pratt student Nicole Norris explains her project to Virginia Tech student Kai Lin.

products, the identification of new research directions, and the creation of a new Wearable Technology Design Research Lab in the Brooklyn Fashion and Design Accelerator, a Pratt sponsored design hub. http://brooklynaccelerator.com/about-bfda/

Student Feedback

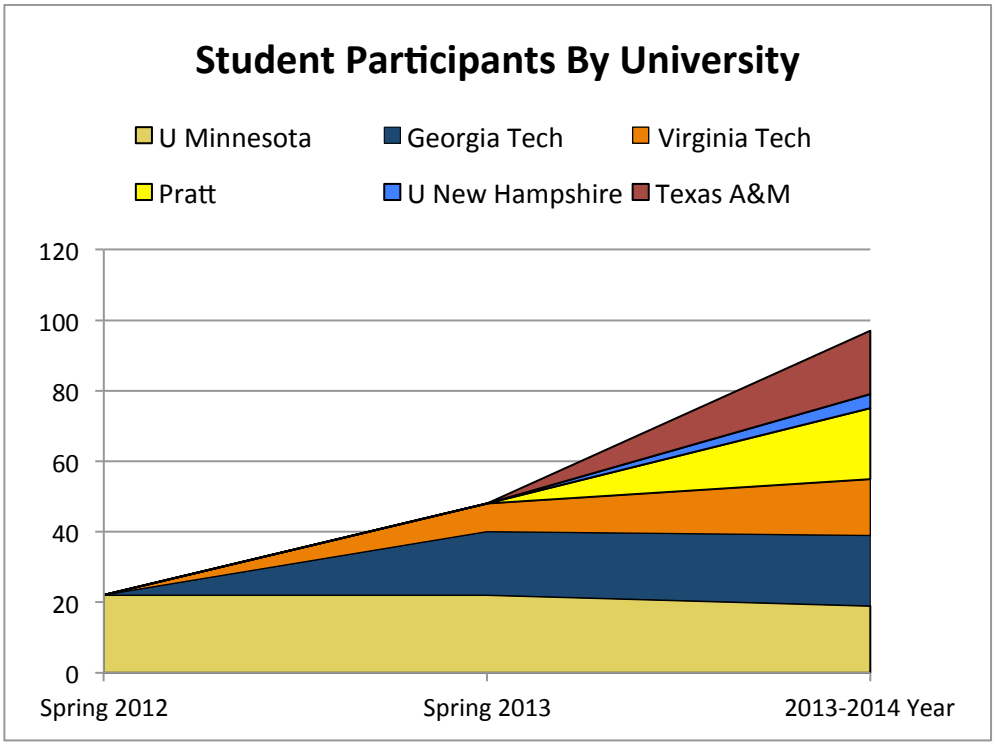
“It was a valuable experience to see the other students’ slide presentations. Engineers have a totally different language than we do as designers. My favorite part was the discussion that followed the presentations, when I was able to talk with the other students about their projects.” - Cody Miller

"This was my first research based design project. It gave me a chance to really understand the user and their environment, which created a solid foundation for the rest of the project to move forward. The research skills I gained will definitely be useful for all of my future projects. Being able to see and discuss the different projects up close was very beneficial. It allowed me to fully understand each group’s project, and even introduce me to technologies that I was unaware of." - Theo Ferlauto

Appendix I – Wearable Technology CLUSTER By the Numbers

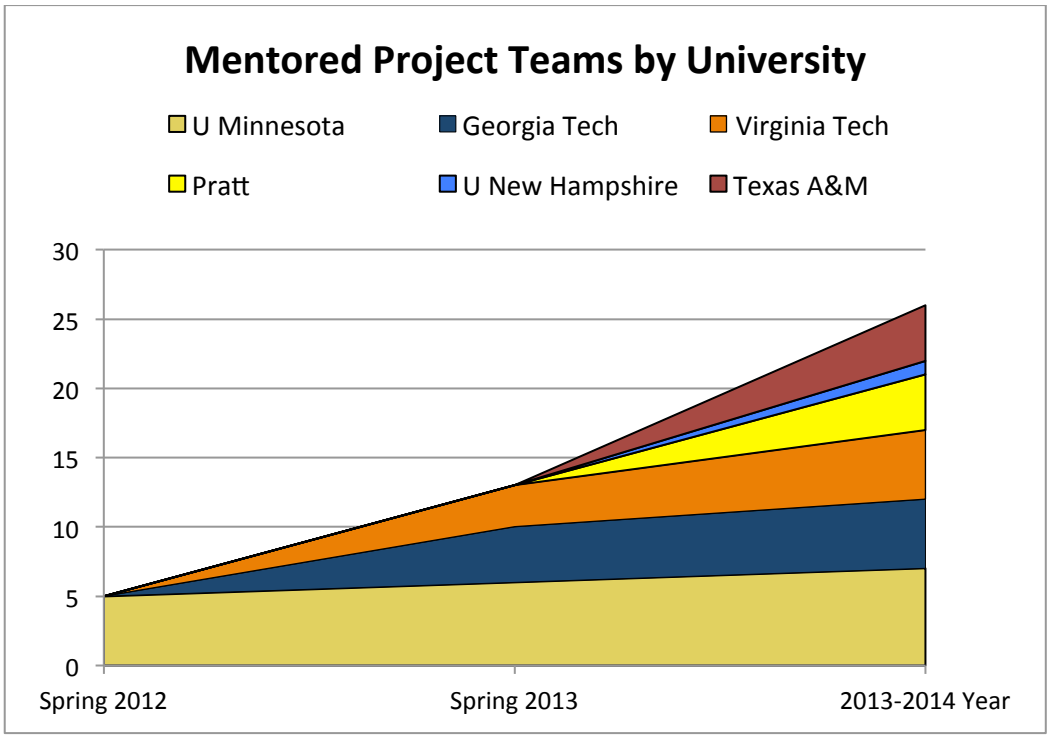
Student Participants by University

Student Participants by University				
			2013-2014	
	Spring 2012	Spring 2013	Fall 2013	Spring 2014
U Minnesota	22	22		19
Georgia Tech		18		20
Virginia Tech		8		16
Pratt			20	
U New Hampshire			4	
Texas A&M			9	9
Semester Total	**22**	**48**	**33**	**64**
Year Total	**22**	**48**		**97**



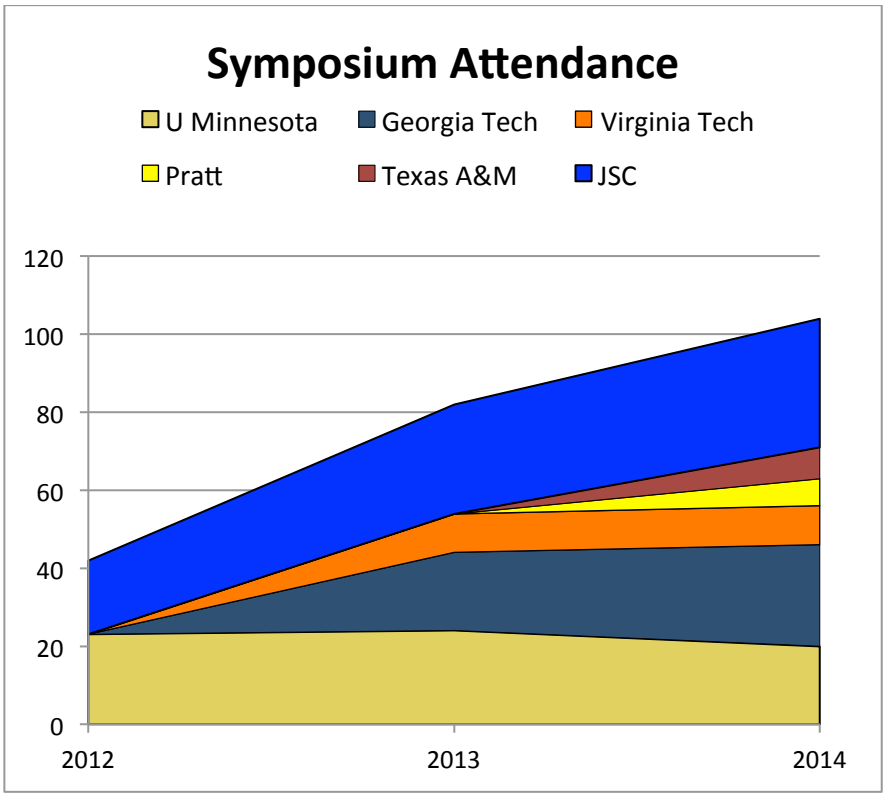
Mentored Project Teams by University

Mentored Project Teams by University				
			2013-2014	
	Spring 2012	Spring 2013	Fall 2013	Spring 2014
U Minnesota	5	6		7
Georgia Tech		4		5
Virginia Tech		3		5
Pratt			4	
U New Hampshire			1	
Texas A&M			1	1
Semester Total	**5**	**13**	**6**	**18**
Total	**5**	**13**		**24**



Symposium Attendance

Symposium Attendance			
	2012	2013	2014
U Minnesota	23	24	20
Georgia Tech		20	26
Virginia Tech		10	10
Pratt			7
Texas A&M			8
JSC	19	28	33
Total	**42**	**82**	**104**



Appendix II – 2012-2014 Student Projects

Semester	Project Title	Mentoring JSC Organization	University
Sp 2014	Haptic Feedback for a Holodeck Testbed	Avionic Systems	Texas A&M (2)
Sp 2014	Wearable Device Attachment	Avionic Systems	Minnesota (2)
Sp 2014	Wearable Sensor Garments for EVA Gloves	Biomedical and Environmental Sciences	Georgia Tech Virginia Tech
Sp 2014	Modified Cargo Transfer Bag Wearable Radiation Shielding Garment	Crew and Thermal Systems	MInnesota Virginia Tech
Sp 2014	Wearable Non-Obtrusive Noise Cancelling Vest	Crew and Thermal Systems	Georgia Tech Minnesota Virginia Tech
Sp 2014	Glove TMG Flexible Cuff Checklist	Crew and Thermal Systems	Virginia Tech
Sp 2014	Posture Sensing Garment	Crew and Thermal Systems	Georgia Tech
Sp 2014	Space Suit External Protective Garment	Crew and Thermal Systems	Minnesota
Sp 2014	One-handed Input Device	Human Systems Engineering	Georgia Tech Minnesota Virginia Tech
Sp 2014	Hands-free Jetpack Controller	Software, Robotics, and Simulation	Georgia Tech Minnesota
Fa 2013	Haptic Feedback for a Holodeck Testbed	Avionic Systems	Texas A&M (2)
Fa 2013	Reconfigurable Functional Garments - E-SEWT Redesign	Avionic Systems	Pratt Institute (4) New Hampshire
Sp 2013	Tactile Display Garments	Avionic Systems	Minnesota (2)
Sp 2013	Garments for Body Position Monitoring and Gesture Recognition	Avionic Systems	Georgia Tech
Sp 2013	Space Suit Moisture Management	Crew and Thermal Systems	Minnesota
Sp 2013	Adaptable Crew Clothing	Crew and Thermal Systems	Virginia Tech Minnesota (2)
Sp 2013	Wearable Sensors to Detect Suit Clearance and Pressure	Human Systems Engineering	Minnesota
Sp 2013	Wearable Controls for a Rover	Human Systems Engineering	Georgia Tech
Sp 2013	Wearable Controls for IVA Ops	Human Systems Engineering	Georgia Tech (2)
Sp 2013	Spacesuit Boot Force Sensing for Hands-Free Jetpack Operation	Software, Robotics, and Simulation	Virginia Tech
Sp 2013	Real Time Fabric Stretch/Shape Visualization for Inflatable Structures	Structures	Virginia Tech
Sp 2012	Reconfigurable E-Textile Garment	Avionic Systems	Minnesota
Sp 2012	Multimodal Caution and Warning	Avionic Systems	Minnesota
Sp 2012	Boot-Foot Indexing	Crew and Thermal Systems	Minnesota
Sp 2012	Liquid-cooling Garment Design	Crew and Thermal Systems	Minnesota
Sp 2012	Wearable Electronics Placement	Human Systems Engineering	Minnesota
Sp 2012	Functional, Comfortable Headwear	Human Systems Engineering	Minnesota

Appendix III – 2014 Wearable Technology Symposium Agenda

Time	Topic/Event	Speaker(s)
8:30 AM	Opening Remarks	Cory Simon Human Interface Branch
8:45 AM	Welcome and JSC Overview	Dr. Kam Lulla JSC University Partnerships Office
9:00 AM	(1) Wearable Sensor Garments for EVA Gloves	Georgia Tech Student Team
9:06 AM	(2) Wearable Non-Obtrusive Noise Cancelling Vest	Georgia Tech Student Team
9:12 AM	(3) Posture Sensing Garment	Georgia Tech Student Team
9:18 AM	(4) Hands-free Jetpack Controller	Georgia Tech Student Team
9:24 AM	(5) One-handed Input Device	Georgia Tech Student Team
9:30 AM	(6) Modified Cargo Transfer Bag - Wearable Radiation Shielding Garment	Minnesota Student Team
9:36 AM	(7) Wearable Non-Obtrusive Noise Cancelling Vest	Minnesota Student Team
9:42 AM	(8) Integration of Space Suit External Protective Garment	Minnesota Student Team
9:48 AM	(9) Hands-free Jetpack Controller	Minnesota Student Team
9:54 AM	(10) Wearable Device Attachment	Minnesota Student Team
10:00 AM	(11) Wearable Device Attachment	Minnesota Student Team
10:06 AM	(12) One-handed Input Device	Minnesota Student Team
10:12 AM	BREAK	
10:24 AM	(13) Modified Cargo Transfer Bag - Wearable Radiation Shielding Garment	Virginia Tech Student Team
10:30 AM	(14) Wearable Non-Obtrusive Noise Cancelling Vest	Virginia Tech Student Team
10:36 AM	(15) Glove TMG Flexible Cuff Checklist	Virginia Tech Student Team
10:42 AM	(16) One-handed Input Device	Virginia Tech Student Team
10:48 AM	(17) Wearable Sensor Garments for EVA Gloves	Virginia Tech Student Team
10:54 AM	(18) Tactile Display Gloves - Human Factors	Texas A&M Student Team
11:00 AM	(19) Tactile Display Gloves - Engineering	Texas A&M Student Team
11:06 AM	(20) Men's E-SEWT with 3-D Printed Swatches	Pratt Student Team
11:12 AM	(21) Men's Close Fit E-SEWT with Iconography	Pratt Student Team
11:18 AM	(22) Unisex Modular E-SEWT	Pratt Student Team
11:30 AM	Dr. Dunne SAM Award Presentation	Dr. Kam Lulla, Steve Stich
11:45 AM	Lunch and Poster Session	
1:45 PM	Advanced Space Suit Development	Amy Ross Advanced Space Suit Development
2:15 PM	Astromaterials and Exploration	Eileen Stansberry Astromaterials and Exploration Director
2:45 PM	Closing Remarks	Cory Simon Human Interface Branch
2:55 PM	Cleanup	
3:05 PM	JSC Onsite Tour for Student Teams	